GREENHOUSE GAS MITIGATION ASSESSMENT FOR VENEZUELA

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1. INTRODUCTION

Geography and Economy

In the context of international initiatives to address global climate change issues, the Government of Venezuela ratified the United Nations Framework Convention on Climate Change (UNFCCC) in December 1994. The Convention requires all parties to develop and publish national inventories of anthropogenic greenhouse gas emissions (GHG) as well as national plans to reduce or control emissions, taking into account "their common but differentiated responsibilities and their specific national and regional development priorities, objectives, and circumstances. Within this context, the Ministry of Environment and Renewable Natural Resources and the Ministry of Energy and Mines developed the «Venezuelan Case- Study to Address Climate Change».

The study was initiated in October 1993, with the financial and technical assistance of the Government of United States, through the U.S. Country Studies Program, and the Global Environment Facility (GEF), through the United Nations Environment Programme (UNEP). The main objectives of the Study are, among others: i) develop a national inventory of anthropogenic emissions and removals of all greenhouse gases (GHG), ii) assess GHG mitigation options, and iii) formulate a national climate change action plan.

This report presents a summary of the mitigation options analysis, whose main objective is to assess the technologies and practices that can potentially contribute to both greenhouse gas emissions reduction and national development efforts (CVCC, 1996). The analysis focuses on CO_2 emissions reduction in the energy and forest sectors.

2. BACKGROUND INFORMATION

Venezuela, located in the northern part of South America, has a total land area of 916,445 km2, divided into 22 states and 1 Federal District. The capital, Caracas, is located in the central northern coastal region, which pioneered the sprout of industries during the 1950s as a consequence of the incentives given during those years to industrial development; therefore, most of the population and major industrial areas are located in this region.

The Venezuelan population grew very quickly in the 1950s — at an annual rate of 4.1%. In the early sixties, the average annual growth rate began to decrease, reaching 3.5% in 1981, and 2.7% in 1990. Currently, the country's population is about 21.8 million inhabitants, mostly located in areas with more than 5,000 inhabitants (81%).

The northwest and northeast regions are the major hydrocarbon producing regions. The most important heavy industries (aluminum and steel) and hydroelectric developments are located in the southern region, while agriculture and animal husbandry are found mainly in the Llanos, and forestry in the southeastern region.

The Venezuelan economy is mainly based on oil, mining, steel, and aluminum export revenues; thus, it is very sensitive to the fluctuations of the international market. The gross domestic product (GDP) has shown significant, clearly defined fluctuations: steady growth until 1972, a sharp increase between 1973 and 1981, and large fluctuations afterwards, including negative growth rates. The jump in oil revenues in the 1970s distorted Venezuela's economy and caused the foreign component of the industrial GDP to increase from 26% in 1968 to 41% in 1978. In spite of the high income, the country incurred a foreign debt of about 30 billion US dollars. Since 1982, the economy has been characterized by adjustments, uncertainties in exchange rate, budget deficits, and increasing inflation problems. However, as a result of a new development program (Agenda Venezuela), the national economy currently shows clear signs of recovery, with substantial flows of foreign investment (mainly in the oil industry), and a downward trend in inflation.

An appreciable change can be noted in the GDP sectoral structure between 1950 and 1995: the oil industry share declined from 64.8% to 27.5%, while the share of other industries and service sector shares have increased from 5% to 15%, and from 25% to 43%, respectively.

The current national development plan (IX Plan de la Nación) include, among others, industrial development programs, improvement of public services, expansion of the petroleum industry (including opening it to foreign investment), and expansion of mining, agriculture and forest activities. All these programs might contribute to increasing greenhouse gas emissions and other environmental problems unless specific effort to address these issues, such as energy efficiency and conservation, are implemented in the near future. Such efforts becomes even more relevant when one considers that industrial activities, transport patterns, and land use change have already generated important environmental problems.

Venezuela still preserves a considerable area of natural forests (more than 50% of the territory) and ranks among the first mega diversity countries in the world. To manage and protect its natural resources, Venezuela has put more than 54% of its territory under various forms of protection. However, implementation of new development programs could also affect extensive forest areas, as the establishment of a wide range of economic activities has been traditionally linked to forest clearing. In this context, the development of the forest sector, if based on sustainable practices, could contribute to both forest conservation and GHG emission reduction, through carbon sequestration and storage.

According to the national GHG emissions inventory (CVCC, 1995), the major sources of CO_2 in Venezuela are the energy combustion (56%) and deforestation (42%). The major sources of methane (CH4) emissions are the energy sector (59%) (mainly from the fugitive emissions of the oil and gas production systems), and the agricultural sector (29%).

The selection of the sectors included in the mitigation options assessment was based on a detailed analysis that took into consideration the contribution of the main sources of the country's GHG emissions, the relevant natural and socio-economic characteristics of the country, the reduction potential, technologies for emission reduction, and local experience in related fields.

The mitigation analysis concentrates on

options to reduce CO_2 emissions generated from the energy sector and land use change. In the energy sector, the analysis was centered on the energy industry, the transportation sector and the manufacturing industry, since these three sectors jointly generate 94% of the CO_2 emissions resulting from energy combustion. For land use change, the mitigation analysis focuses on the forest sector.

3. ENERGY SECTOR

The mitigation analysis of CO_2 emissions from the Venezuelan energy system indicates that the highest reduction potential exists in the transportation sector, electricity generation, and the manufacturing industry, mainly through improved energy efficiency amd fuel switching. The assessment of some mitigation options in these sectors indicates that there are alternatives which, in addition to contributing to GHG emissions reduction, provide economic benefits for the energy system.

National Energy System

Venezuela has diverse and abundant energy resources. The total volume of proven energy reserves in 1995 was 112.5 billion barrels of oil equivalent (BOE), of which oil represented 63.8%, natural gas 28.1%, hydroenergy 0.2%, and coal 7.9%. Venezuelan oil proven reserves represent 6.4% of world oil reserves and 8.3% of OPEC country reserves, while natural gas represents 2.9% and 6.6%, respectively. Currently, extra heavy crude oil represents 46% of national proven reserves, heavy oil 24%, and medium and light oil 30%. The technical potential of renewable energies in Venezuela (including solar, wind, biomass, geothermal and mini-hydro energy), has been conservatively estimated at over 4 million BOE/day.

Oil production decreased from 1970 to the beginning of the 1990s, due to a significant drop in crude oil and products export, from 3,785 thousand BOE per day in 1970 to 2,352 thousand BOE per day in 1994. This was a consequence of the OPEC's strategy to control oil production in order to avoid a drop in oil prices.

The total domestic consumption of oil products increased from about 200 thousand barrels per day in 1970 to 400 thousands in 1980. However, this consumption has remained relatively stable since 1980, reaching 487 thousand barrels per day in 1994. Domestic consumption of natural gas increased steadily throughout this period.

Oil, gas, and coal production is conducted by one publicly owned company, Petróleos de Venezuela S.A. (PDVSA), which is in charge of top management and is responsible for the industry's operation, through its eight affiliates.

Electricity service is provided by five public and seven private utilities. Power generation capacity increased from 2,677 MW in 1970 to 18,613 MW in 1994. The ratio of thermal to hydro capacity, which was 68/32 during the 70' decade, was 24/76 in 1994, mainly due to the completion of Guri hydropower plant. The population that had access to electricity services jumped from 60% in 1970 to 90% in 1994.

The annual growth rate of final consumption during the 1970s was about 6%, dropped to about 2% in the 1980s, and increased in the 1990-1994 period. The main changes in the structure of final energy consumption over the last 20 years have been: (i) an increased share of natural gas share in industrial consumption, from about 45% in 1970 to almost 52% in 1994, (ii) increased share of LPG in household consumption from less than 10% in 1970 to almost 40% in 1994, and (iii) an increased share of electricity in total final consumption from 7.9% in 1970 to 14% in 1994 overall, and from 26% to almost 50% in the household sector.

Although the country possesses significant renewable resources, their share (excluding hydroenergy) in total final energy consumption has been less than 1% — primarily from firewood and charcoal. The low price of conventional energy has restrained the development renewable energy. From 1960-1989, the national energy pricing policy was designed, in accordance with the country's economic policy, to promote industrial development. Energy prices were at their production costs levels and in direct subsidies were applied in some cases. This policy had very negative effects on the energy system itself, inducing wasteful and irrational use of energy.

After the oil price crisis in 1983, it became clear that this policy could not be longer sustained. However, because of political and social concerns, it was maintained at a very high cost until 1989, when the government launched a new economic program. The aim of this energy pricing program was to gradually equalize domestic energy prices with their opportunity costs (FOB prices), for tradable goods (petroleum products), or with their marginal costs for non-tradable goods (electricity and natural gas).

Methods

GHG mitigation assessment includes selecting options and evaluatiing their impacts, including associated costs, on CO_2 emissions and the energy system . The main barriers and the necessary policies for implementing the options were also identified. An integrated study of the national energy supply and demand systems was carried out in order to identify, evaluate, and compare possible mitigation options.

Two scenarios were considered following the Guidelines for Mitigation Assessments (Sathaye and Meyers, 1995): i) a baseline scenario, which describes the possible future of Venezuelan energy system, in which no specific actions to reduce GHG gas emissions will be taken; this scenario includes adoption of some enhanced technologies and actions to obtain a greater efficiency in the use of resources; and ii) a mitigation scenario, which describes a similar future to that of the baseline scenario regarding the evolution of macroeconomic and social aspects, but assumes that efforts will be made to encourage the adoption of mitigation measures.

The assessment included the following activities: development of macroeconomic scenario; projection of baseline energy demand using the LEAP model (SEI-B,1993); evaluation of the power system expansion, using the ELECTRIC module of the ENPEP model (ANL-EESD,1994) and PLHITER model; construction and projection of the energy system's supply and demand network using the BALANCE module of the ENPEP model; estimation of the baseline scenario parameters; identification and assessment of potential mitigation options; impact assessment of several mitigation options with the BALANCE module; and identification of barriers and feasible mitigation options.

The "Long Range Energy Alternative Planning" (LEAP) model was developed at the Tellus Institute. It allows the construction of several economic growth scenarios that can be translated into different energy demand forecasts. The "Energy Planning and Power Evaluation Program" (ENPEP) model is a microcomputer energy planning package developed by Argonne National Laboratory;. It consists of ten technical modules and one executive module. The modules used for the mitigation assessment of the Venezuelan energy sector were: BALANCE, which is based on an equilibrium model, was used to project the balance of energy supply and demand within a study period of more than 30 years; and ELECTRIC, which calculates an expansion plan of the power generation system, at a minimum cost.

CO_2 emissions were estimated per fuel, using the emission factors of the IPCC methodology. The cost-benefit evaluation was conducted with the BALANCE module results.

The mitigation costs are the incremental costs for implementing mitigation options, calculated as the difference between the costs in the mitigation and the baseline scenarios. These incremental costs result primarily from the additional costs that the final user has to cover, the differences in energy supply costs as a result of changes in the final consumption, and the supplier's income differences in both the domestic and exportation markets resulting from the implementation of a specific mitigation option. Final user costs consider fuel, operation and maintenance, and capital costs. The BALANCE module provides results for each of these costs per year throughout the study period. They are discounted to 1990 at 10% rate and then aggregated in order to get the total mitigation cost for the whole period.

The Venezuelan Energy System Network

The Venezuelan energy system network was simulated with the BALANCE module. Figure 3.1 shows a general outline of the main components of the energy supply and demand areas. Figure 3.2 shows the supply network structure, outlining the types of resources available, the processes used in their production, and their transformation into secondary energy as well as the products obtained.

The demand area was developed beginning with the streams of the various fuels to the end consumption sectors, which were separated into sub-sectors that show an energy behavior that is differentiated either by the fuels used, energy uses or future demand. The consumption by type of fuel in each sub-sector was broken down by energy uses.

The energy demands, which constitutes the network's last level, was expressed in terms of the useful energy required for each use in every sub-sector, except for the transportation sector, where transport demands (passenger-kilometers and ton-kilometers) were used.

The different fuels that meet these demands converge through processes which represent the conversion of final energy into useful energy; these processes are characterized by the conversion efficiency and the technology type and cost. Figure 3.3 shows the demand network structure outlining the desegregation by sub-sectors and the uses of energy considered for each sector.

The 1990 National Energy Balance and the 1993 MEM/RISO/UNEP study were used for the simulation of the energy system network for the base year. The estimates of costs and prices were based on date provided by MEM and PDVSA. The results obtained from the BALANCE model for the base year reflect differences of between 2-3%

Figure 3.1
Energy Systems Network Structure

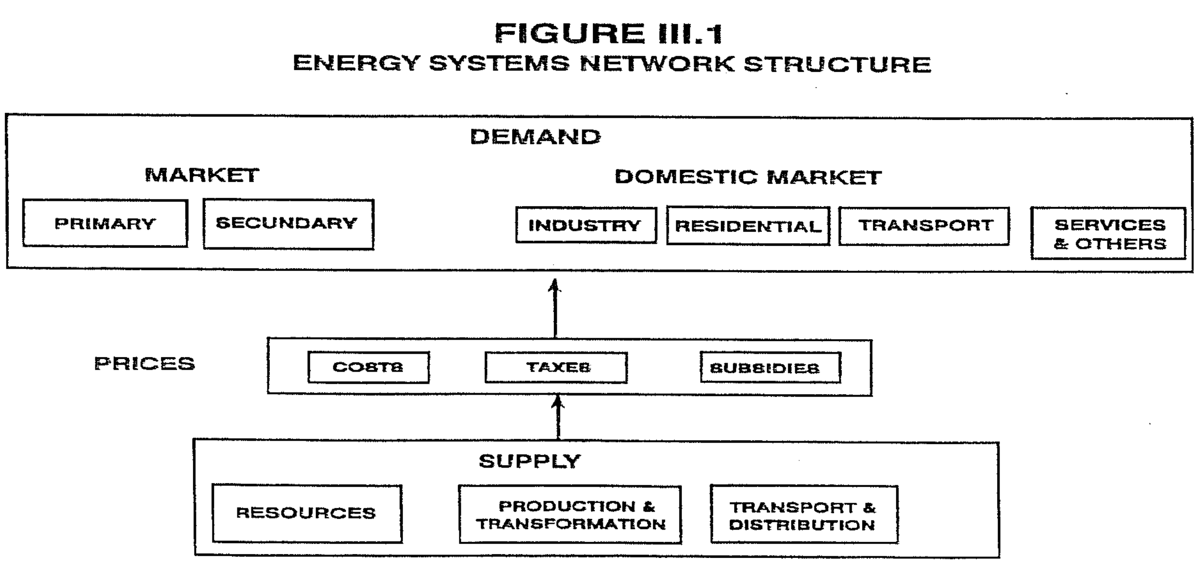


Figure 3.2
Supply Network Structure

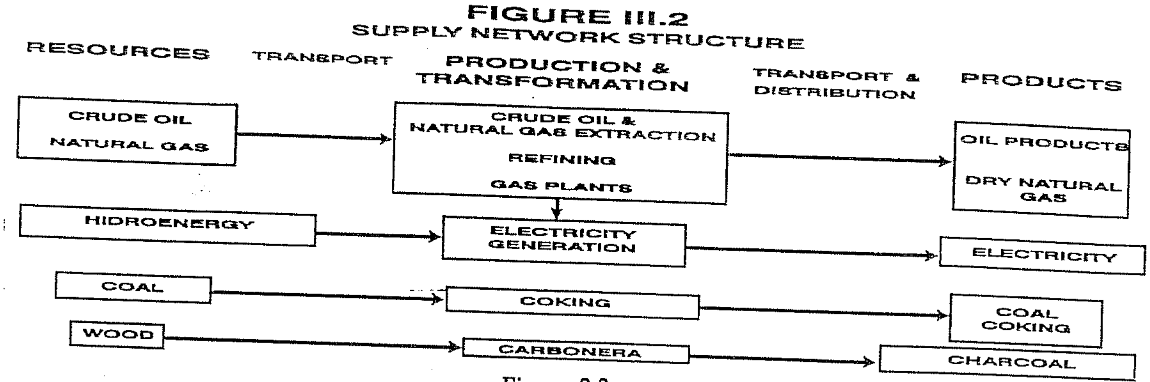


Figure 3.3.
Demand Network Structure

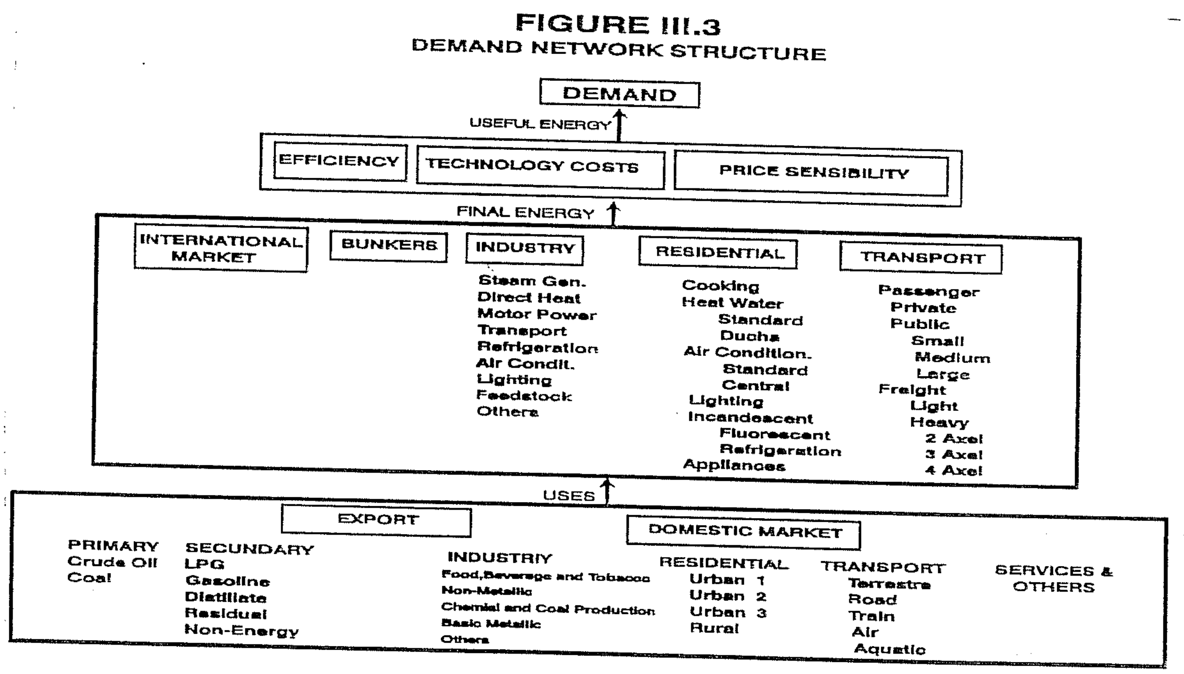
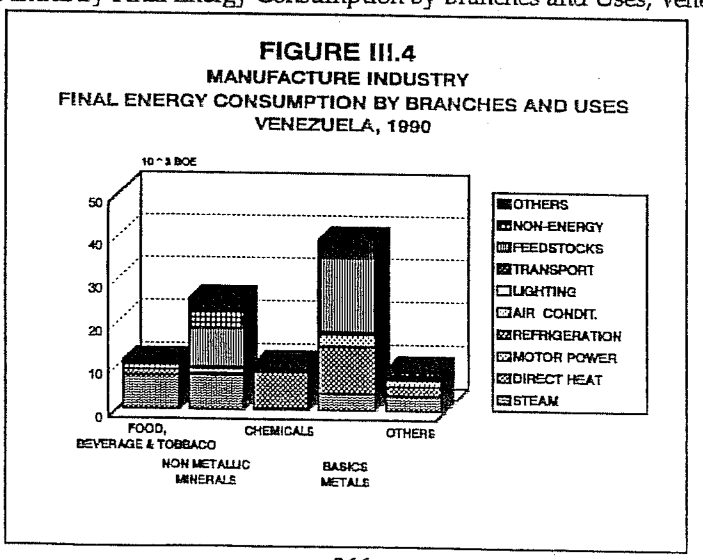


Figure 3.4.
Manufacture Industry Final Energy Consumption by Branches and Uses, Venezuela, 1990



with respect to the data provided. These differences may be regarded as acceptable since the prospective assessments are generally based on a series of assumptions where this margin of error is irrelevant.

The industrial sector was broken down in accordance with two-digit groups of the International Standard Industrial Classification (ISIC). The energy consumption of each fuel used in these groups was separated into the most important final uses. For that purpose, information obtained from the Manufacturing Industry Energy Survey (MEM/OCEI, 1990) was used. Sectoral consumption is represented by 45 demand nodes. Figure 3.4 shows energy consumption by branches and uses. For the transportation sector, consumption of each fuel was separated by transportation mode and type of vehicle. Each type of vehicle was separated into "old" and "new" vehicles. "Old" vehicles include the entire stock in 1990 and "new" vehicles are those that began to circulate after that year. The energy consumption data were obtained from estimates made by Pulido (1990) and MEM/RISO (1994). Figure 3.5 shows the distribution of the road transportation sector's consumption during the base year and reflects the importance of passenger transportation.

The residential sector was subdivided into three urban areas and one rural area. The urban areas differ according to the populations' standard of living, which also characterizes and differentiates energy consumption and its development. The uses of energy specified in Figure 3.3 are considered for each area, and the sector demand is expressed in terms of useful energy through 24 demand nodes; one for each use in each node. Figure 3.6 shows each area's consumption distribution by use.

Baseline Scenario

The baseline scenario for 1990-2025 was based on a macroeconomic scenario that assumes sustained economic development, where the barriers that currently restrict the country's economic development will be overcome but without major structural changes taking place. The oil industry reduces its participation in the gross domestic product (GDP), while the manufacture industry increases its share as a result of the development of the aluminum and petrochemical industries. A moderate decrease in the contribution of the service sector is also assumed. Regarding demographic

Figure 3.5.
Road Transportation, Final energy Consumption by Mode, Venezuela, 1990 (65329.6 10^3 BOE

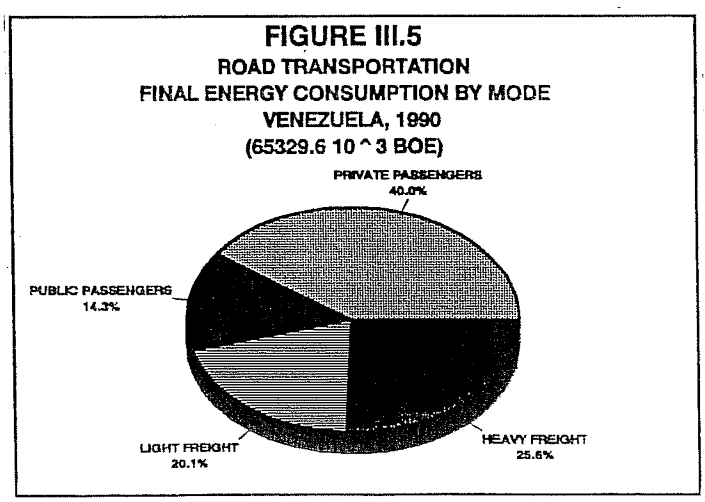
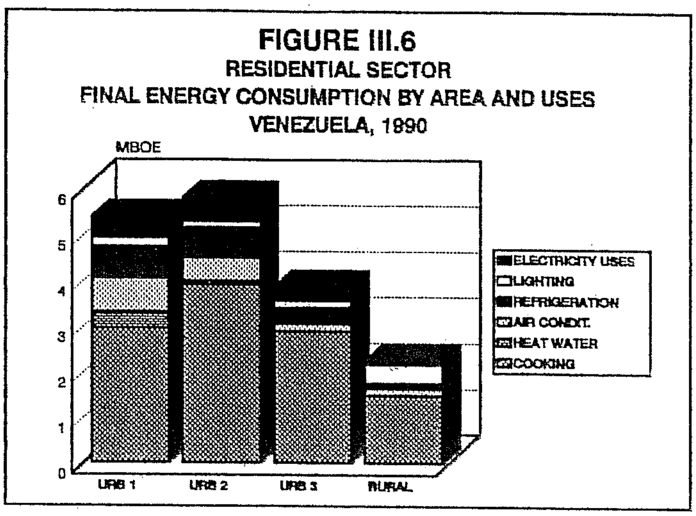


Figure 3.6.
Residential Sector Final Energy Consumption by Area and Uses, Venezuela, 1990



assumptions, a reduction in population growth rate and few changes in income levels structure are assumed. Table 3.1 shows the main parameters of this scenario.

In the sectoral energy demand scenarios, changes in energy use intensities are assumed as a result of improvements in equipment efficiency, better energy management, and changes in life style. In the simulation, energy prices gradually increase until they reach their opportunity cost (FOB export costs) in the case of oil fuels, or their production marginal cost, in the case of natural gas and electricity, in 1996. However, this policy has not been fully implemented due to social and political implications.

The scenario assumes that there will be transformations in the energy system as a result of economic development, but no further efforts will be made to establish specific policies or measures to control or reduce greenhouse gas emissions.

Table 3.1.
Baseline Scenario Assumptions

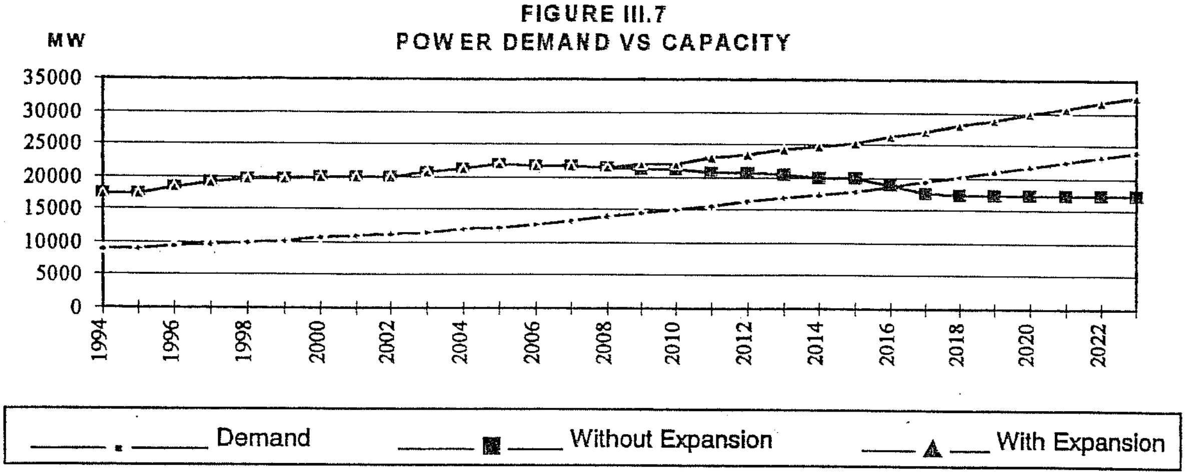
	Period	Growth (%)
Population	1990 - 2025	2.1
GDP	1990 - 1995	2.2
	1995 - 2000	3.5
	2000 - 2005	3.9
	2005 - 2025	4.5
GDP Share (%)	1990	2025
Oil Industry	28	24
Other industries	14.7	17
Services	43	42
Other Activities	57	59

Supply Side

A national electricity expansion plan for 1994-2023 was developed (Jimenez, 1996) with the participation of the national electric sector institutions, including utility companies, which provided the required data for this study. The demand for electricity will grow 3.85% annually from 1994-2001 period and will then be maintained at 3.6% for the rest of the period. Figure 3.7 compares the power capacity without expansion with the estimate of power demand. As the figure shows, both parameters coincide in 2016.

Using the ELECTRIC Module of the ENPEP Model, twelve cases were analyzed using three hydroconditions and four variants for each hydrocondition. The alternative with the lowest cost and the lowest risk is that which considers the recovery and reconditioning program for the thermal stock, the start-up of Caruachi hydro power plant in the year 2003, and the hydrocondition of a rainy year. Figure 3.7 shows the results of the installed capacity expansion for this case. Hydroenegy generation increases up to the year 2011, and from then

Figure 3.7.
Power Demand vs. Capacity



on increases correspond to thermal generation with natural gas.

The assumptions on oil and gas supply are based on the expansion plans of the national oil industry, which takes into account increases in the production and capacity of all sources.

Demand Side (MEM/RISO/UNEP, 1993)

Industrial Sector. The main assumption is the maintenance of the base year structure for the whole study period, in relation to final use and energy source split. Energy intensities by final use will change over the study period, depending on the final use, regardless of the industrial branch in which the change takes place. However, this evolution deals mainly with improvements of energy efficiency of final equipment, since structural changes and fuel switching are accounted for by other indicators.

Transportation Sector. The evolution of passenger-kilometers (PKm) and tonne-kilometers (TKm), was built bearing in mind the ratio of those parameters to total population in industrialized countries during the 1980s. To achieve such levels by the end of the study period, those parameters will have to increase faster than population growth.

The structure of each transport branch by mode will change slightly over time and the maintenance of each transport mode structure by vehicle age and fuel is assumed. Neither relative aging nor renewal of the vehicles stock is considered. The average fuel consumption will change as a result of improvements in the vehicle energy efficiency, changes in habits, management measures undertaken by transport companies, etc.

Residential Sector. The main assumption for the future development of this sector is the maintenance of the base year level of each final use penetration for all income levels. The main changes are: (i) a relatively high level of penetration of natural gas devices wherever is possible (cooking, water heating and air conditioning), (ii) a small penetration of solar energy for water heating, and (iii) a significant increase in the share of improved equipment for all possible uses.

Results

Primary energy production, which was 1000 million BOE in 1990, would double by year 2010 and would be 4.6 times higher by 2025. Table 3.2 shows that this high increase, which reaches 4.4% annually, is primarily due to fossil fuel production, encouraged by exports that grow at about

Table 3..2.
Primary Energy Production, Baseline Scenario (10^3 BOE)

Year	1990	1995	2000	2005	2010	2015	2020	2025
Crude oil	834126	1005187	1230066	1509317	1872833	2338686	2925804	3662565
Natural gas	132975	160245	196095	240613	298564	372829	466427	583881
Coal	11188	16900	26195	41119	65106	103698	165800	265769
Hidroenergy	22264	35624	42450	49386	51094	52261	50582	53221
Total	1000553	1217956	1494806	1840435	2287597	2867474	3608613	4565436

5.0% per year. As it can be seen in Table 3.3, final consumption of fossil fuels and electricity generation grow at 3.3% and 2.6% per year, respectively.

Final energy consumption, 189 million BOE in 1990, would almost double by the year 2010 and would almost triple by the year 2025. This represents a growth of 3.3% annually during the period, which is lower than the average growth assumed for the GDP (4.0%). Final fossil fuel consumption grows at 3.3% annually, while electricity consumption grows at 3.0%. Natural gas shows the highest growth (4.2% per year), increasing its share of the total final consumption from 33.0% in 1990 to 44% in 2025.

With respect to energy consumption by sector, the industrial sector shows the highest growth, with an annual rate of 4%. The consumption growth of the residential, services, and other sectors is moderate (1.6%) and is below the assumed population growth. The transportation sector increases 2.7% per year, which is just over the population growth but lower than the GDP growth rate.

Table 3.4 shows the estimates of $C0_2$ emissions generated by the energy sector activities, distributed by sectors and fuel type. The growth of emissions from final energy consumption (2.9%) is lower than energy consumption, which is mostly due to a increased use of natural gas instead of liquid fuels that have a higher carbon content.

Mitigation Options Assessment

Industrial Sector

Given the importance of steam generation and direct heat in energy consumption and greenhouse gas (GHG) emissions from the industrial sector, an analysis of several mitigation options for these energy uses was conducted.

Steam Generation. The mitigation options considered aim to increase the average boiler efficiency and the use of fuels with lower carbon content. This study analyzed two mitigation options for boilers that are operating in the following branches (ISIC): 31- foods, beverages, and tobacco; 35 - chemicals and coal; and 37- basic metals, which together consume 82% of the energy used in steam generation. The options are: boilers conversion from liquid fuels to natural gas, and improving the efficiency of existing natural gas boilers through annual maintenance programs.

In the baseline scenario, only the incorporation of new natural gas burning boilers is considered to meet the steam increase requirements in this sector. This slightly increases the average efficiency of the equipment. Yearly energy growth rates of 3.1%

Table 3.3.
Fossil Fuels Uses, Baseline Scenario (10^3 BOE)

Year	1990	1995	2000	2005	2010	2015	2020	2025
Exports	718941	889732	1108915	1387752	1743383	2198904	2785910	3518514
Final consumption	188523	220203	252327	290749	342178	408137	490869	587240.3
Electricity generation	53184	17719	15116	16998	40167	64318	98520	130141
Total	960648	1127654	1376358	1695499	2125728	2671359	3375299	4235895.3

Table 3.4
CO_2 Emission, Baseline Scenario (10^3 Ton)

Year	1990	1995	2000	2005	2010	2015	2020	2025
Final consumption by sector								
Industry	24818	30110	36174	43780	53306	65036	79826	94600
Transport	29180	33001	35945	38832	44142	51956	61658	73216
Residential	4272	4674	4973	5444	5866	6428	7048	7449
Total	58269	67785	77091	88056	103315	123419	148532	175265
Final consumption by fuel								
Oil	38347	43064	46731	50700	57347	66879	78853	89741
Natural gas	18951	23695	29285	36229	44785	55294	68362	84126
Coal & coke	972	1026	1076	1128	1183	1246	1317	1398
Electricity	0	0	0	0	0	0	0	0
Biomass	0	0	0	0	0	0	0	0
Total	58269	67785	77091	88056	103315	123419	148532	175265
Electricity generation								
Diesel	972	0	0	0	0	0	0	0
Residual	5411	0	0	0	0	0	0	0
Natural gas	13182	6007	5196	5906	14079	22744	33075	43659
Total	19565	6007	5196	5906	14079	22744	33075	43659

for the steam-generated useful energy in the foods branch and 3.8% for the chemical and basic metals branches were assumed. The characteristics of the boilers were monitored in order to determine a representative equipment for each industrial branch per type of fuel, as specified in Table 3.5.

Option 1: Boilers Conversion from Liquid Fuels to Natural Gas

This option primarily deals with burner substitution and the installation of pressure regulators and automatic valves, allowing the natural gas to reach the burner under the necessary technical conditions. Efficiency of the converted natural gas boiler reaches 85%. Implementation of this option is assumed to begin in the year 2000 and finish by 2005, by which time all liquid fuel boilers would be replaced. Table 3.6 shows the investment and operation costs involved in the application of this mitigation option. Table 3.7 summarizes energy savings, CO_2 emissions reduction, and the final user costs, which decrease.

Option 2: Natural Gas Boiler Maintenance Program

Combustion adjustment is one of the measures increases boiler efficiency. This

Table 3.5
Characteristics of Boilers

Industrial Branch	Fuels	Power HP	Nominal Capacity 10^3 BOE/year	Use %	Efficiency %	Investment 10^3 $/Plant	O&M Cost $/BOE	Life Years
Food, beverage & tobacco	Bagasse	-	100	90	48	1	1.00	20
	Natural gas	400	14.80	80	75 (*)	80	0.14	30
	Diesel	250	5.50	80	58	58	0.58	30
	Fuel oil	250	5.50	80	58	58	0.58	30
	LPG	250	9.20	80	70	58	0.23	30
Chemicals	Natural gas	300	11.10	80	75 (*)	65.2	0.19	30
	Diesel	150	3.32	80	58	41	0.96	30
	Fuel oil	150	3.32	80	58	41	0.96	30
	LPG	150	5.54	80	70	42.8	0.38	30
Basic metals	Natural gas	>1500	587	83	86	7207	2.77	30
	Diesel	150	3.32	80	58	41	0.96	30
	Fuel oil	150	3.32	80	58	41	0.96	30
	LPG	150	5.54	80	70	42.8	0.38	30
	Coal	-	3.32	80	50	41	0.96	30

(*) The natural gas boilers will have a mean efficiency of 77% from year 2000, due to new equipment acquisition.

Table 3.6
Investments and Characteristics of Boilers Conversion from Liquid Fuels to Natural Gas

Industrial branch	Power HP	Investment 10^3 $/plant	O&M Cost $/BOE	Efficiency %	Capacity 10^3 BOE/year
Food, beverage & tobacco	250	10.03	0.23	85	5.54
Chemicals	150	9.43	0.38	85	3.32
Basic metals	150	9.43	0.38	85	3.32

Table 3.7
Boilers Conversion Mitigation Option Results

Year	2000	2005	2010	2015	2020	2025
Energy consumption for steam generation (10^3 BOE)						
Baseline	24531	29013	34325	40863	48587	57706
Energy saving	101	498	458	463	1764	1835
%	0.4	1.7	1.3	1.1	3.6	3.2
CO2 emissions (10^3 Ton)						
Baseline	7921	9318	11019	13109	15608	18646
C02 reduction	71	333	303	309	327	386
%	0.9	3.6	2.6	2.4	2.1	2.1
Final user costs (10^6 $)						
Baseline	166	192	263	313	438	525
Mitigation	-3.8	-19.7	-17.3	-18.5	-19.5	-24.6
%	2.3	10.3	6.6	5.9	4.3	4.5

adjustment consists in obtaining the correct oxygen-fuel mixture in order to have a complete combustion, according to the type of burner used.. In addition, the maintenance program includes: eliminating steam leaks and sealing chamber oxygen, cleaning the fireside boiler tube, repairing refractors, adjusting and cleaning burners, and adequate inspecting control and safety devices.

Implementation of this option is assumed to begin in 2000, initially on 20% of existing boilers, and progressively extended up to 2004, when all the boilers would have been covered. This option will only be adopted in branches 31 and 35, where natural gas boiler efficiency is about 78% and is supposed to increase up to 82%.

The operating and maintenance costs for each year and the increased boiler efficiency as a result of the mitigation measure are shown in Table 3.8. Table 3.9 shows energy savings, C02 emissions reduction, and final user costs, which decrease.

Direct Heat. In 1990, basic metals industries (branch 37) accounted for 41% of the total energy consumption in the manufacturing industry and 50% of direct heat consumption. The steel and aluminum industries consume almost all of the total energy for direct heat in branch 37. Thus, two mitigation options were formulated for these industries: changes in iron mineral reduction, and combustion efficiency improvement in natural gas furnaces for foundry and lamination.

The baseline scenario considers development of the steel and aluminum industries under the following assumptions: energy demand for direct heat will increase at an annual rate of 4.2%, there will be no actions concerning relevant changes in processes, and there will be some improvement in energy efficiency due to the renewal and introduction of new equipment. Table 3.10 shows the general characteristics of direct heat equipment under assessment.

Option 3: Changes in Direct Reduction of Iron Ore

Table 3.11 shows the characteristics of technologies available in the Venezuelan steel industry. The "H&L" and "Midrex" technologies are considered in the mitigation analysis because they are the most

Table 3.8
Operating and Maintenance Costs and Boilers Efficiency Improvement for Natural Gas Boilers Maintenance Program

Industrial branch	Year	2000	2001	2002	2003	2004	2005-2025
Food, beverage & tobacco	O & M Costs $/BOE	0.15	0.16	0.18	0.19	0.20	0.20
	Efficiency %	78	79	80	81	82	82
Chemicals	O & M Costs $/BOE	0.21	0.22	0.24	0.25	0.27	0.27
	Efficiency %	78	79	80	81	82	82

Table 3.9
Natural Gas Boilers Maintenance Program Mitigation Option Results

Year	2000	2005	2010	2015	2020	2025
Energy consumption for steam generation (10^3 BOE)						
Baseline	21089	24838	29270	34742	41177	48733
Energy saving	228	1325	1604	1928	2309	2759
%	1.1	5.3	5.5	5.6	5.6	5.7
CO2 emissions (10^3 Ton)						
Baseline	6751	7901	9303	11030	13091	15598
C02 reduction	76	447	543	656	787	944
%	1.1	5.7	5.8	6.0	6.0	6.1
Final user costs (10^6 $)						
Baseline	135.4	154.4	211.5	249.8	350.9	419.5
Mitigation	-1.0	-6.0	-9.5	-11.8	-17.7	-21.5
%	0.7	3.9	4.5	4.7	5.0	5.1

Table 3.10
Characteristics of Direct Heat Equipment

	O & M Costs ($/BOE)	Investment (Million $)	Capacity per Standard Unit (10^3 BOE/year)	Use %	Efficiency %
Direct reduction furnaces in steel industry	4	130	850	75	61
Rest of natural gas furnaces in steel & aluminum industries	50	1.2	80	80	40

Table 3.11
Direct Reduction Iron Technologies in Venezuelan Steel Industry

Technology	" H & L "	" Midrex "	" Arex "	" Fior "	" Finmet "
Product	DRI	DRI	DRI	HBI	HBI
Capacity 10^3 Ton/year	2,163.00	1,630.00	450.00	400.00	1,000.00
Production 10^3 Ton/year	1,172.00	1,615.00		404.00	
Present state	Operation	Operation	Project	Operation	Project
Input	Lump/Pellets	Lump/Pellets	Lump/Pellets	Fine	Fine
Furnace type	Reducing Shaft Batching Process	Reducing Shaft Continuous Process	Reducing Shaft Continuous Process	Fluid Bed Continuous	Fluid Bed Continuous
Gas treatment	Reforming	Reforming	Auto Reforming	Reforming	Reforming
Pressure	5 Bar	Atmospheric	Atmospheric	10 Bar	10 Bar
Specific energy consumption					
Natural gas BOE/Ton	4.86 (1)	2.04 (1)	1.86 (2)	3.01 (2)	3.17 (2)
Electricity BOE/Ton	0.08 (1)	0.06 (1)	0.05 (2)	0.12 (2)	0.09 (2)

(1) Actual values

important in terms of capacity and production. When analyzing their natural gas specific consumption per ton of production, a significant difference is observed (4.86 BOE/Ton and 2.04 BOE/Ton). This difference arises because the actual value of the "H&L" technology is more than double the theoretical value (2.1 BOE/Ton) and because "H&L" is the oldest reduction technology and did not achieve the full design production levels. Thus, CO_2 emissions reduction could be obtained through energy efficiency improvement of the "H&L" technology or a conversion or substitution process to more efficient technologies. Furthermore, the Midrex technology could also be improved.

The basic assumptions for this mitigation options are:

Efficiency improvement
2000- 2025 "H&L" from 43% to 73%
"Midrex " maintained at 80%
Technology change
2005 First stage of the "H&L" to the"Midrex" ($363*10^3$ Ton/year).
2010 Second stage of the "H&L" to the "Midrex" ($1800*10^3$ Ton/year)
2015 Improvement of the "Midrex" Technology
Investments required

Year	2000	2005	2010	2015	2025
US$M	30	200	255	280	0

Investment values are based on company estimates and initial investments to begin this process. However, they are subject to review due to uncertainties. Table 3.12 shows energy savings, C02 emissions reduction, and the final user costs obtained for this option.

It is important to bear in mind that this analysis considered only savings from natural gas used as fuel, which represents part of the potential of energy savings and emissions reduction potential. If savings from process gas were included, the emissions reduction potential would be higher because when this gas is used only 12% of the carbon is sequestered, the rest is emitted. Thus, mitigation costs per ton of CO_2 might be considerably reduced.

Option 4: Efficiency Improvement in Natural Gas Furnaces

In this mitigation option, a typical furnace with its specific characteristics was based on reheating lamination furnaces for steel products and furnaces for aluminum alloys. The theoretical thermal efficiency of furnaces was found to be low.

Basic assumptions are:

- Energy efficiency increases from 42% to 70% (2000-2025)
- Yearly operation and maintenance costs increase by 20$/BOE in year 2000.
- Investments of US$ 400 thousand in year 2010.

Table 3.12.
Direct Reduction Iron Mitigation Option Results

Year	1990	2000	2005	2010	2015	2020
Energy consumption (10^3 BOE)						
Branch 37 (Baseline)	11830	17325	21104	25544	31195	36632
Process (Baseline)	3881	5923	7305	9003	11088	13095
Energy saving	0	278	752	2387	3131	3698
% / Branch 37	0%	1.6%	3.6%	9.3%	10%	10%
% / Process	0%	4.7%	10.3%	26.5%	28.2%	28.2%
CO2 emissions (10^3 Ton)						
Branch 37 (Baseline)	2840	3928	4684	5542	6665	7745
Process (Baseline)	1302	1987	2451	3020	3720	4393
Reduction	0	93	252	801	1050	1241
% / Branch 37	0%	2.4%	5.4%	14.5%	15.8%	16%
% / Process	0%	4.7%	10.3%	26.5%	28.2%	28.2%
Final user costs (million $)						
Branch 37 (Baseline)	972	1541	1803	2151	2556	3623
Process (Baseline)	82	118	139	172	202	276
Mitigation	0	17	46	86	129	138
% / Branch 37	0%	1.1%	2.6%	4.0%	5.0%	3.8%
% / Process	0%	14.4%	33.1%	50.0%	63.9%	50.0%

Table 3.13 shows energy savings, CO_2 emissions reduction and the final user costs.

Transportation Sector

Big cities in Venezuela have high vehicle densities and low fuel efficiency, mainly due to fleet age, poor maintenance, and high traffic volume. In order to accelerate fuel efficiency improvements in the transport sector, the Venezuelan government is developing an ambitious plan, initially focused on the public transport fleet.

Three mitigation options were studied in detail: switching to larger capacity vehicles, reduced private vehicles share, and switching from gasoline to natural gas vehicles.

The baseline scenario considers a road vehicle fleet of 2.7 million units in 1990, where passenger vehicles represent 81%, and freight vehicles 19%. Table 3.14 shows the basic information by vehicle type. The average transportation demand growth rate for 1990-2025 period is assumed to be 3.4% per year for both passenger-km and tonne-km.

Private vehicles represented 33.2% of the total passenger demand in 1990 and their share is assumed to grow to 40% by 2025. Public transportation share is assumed to decrease from 62.5% in 1990 to 56% by 2025. In this segment, small buses decrease from 25% in 1990 to 22% by 2025. Railroads maintain a small share of about 3.5%. Freight transportation maintains the same structure along the 1990-2025 period; the share of light 2 axle trucks is about 7%, of heavy 2 axle trucks 14%, of 3 axle trucks 43%, and of 4 axle trucks 36%.

Option 5: Switching to Larger Capacity Vehicles

This option considers switching public transportation from small buses to large buses and assumes a switch from light duty trucks to heavier trucks. The main assumptions are:

-Private and public transport share in total passenger transportation demand are the same as in the baseline scenario. The share of public transportation presents the following intermode change:

- small buses disappear by 2010.
- the annual growth rate of medium buses from 1990-2025 changes slightly from 3.03% in the baseline case to 2.85%.
- large bus share increases from 23% in 1995 to 35% in 2025, which represents an increase in annual growth from 3.3% per year in the baseline case to 4.7%.

The demand share of two axle light duty vehicles decreases from 8% in 1990 to 1.6% in 2025, while in the baseline scenario their

Table 3.13.
Furnaces Using Natural Gas Mitigation Option Results

Year	1990	2000	2005	2010	2015	2020
Energy consumption (10^3 BOE)						
Branch 37 (Baseline)	11830	17325	21104	25544	31195	36632
Furnaces (Baseline)	1586	2374	2959	3511	4353	5164
Energy saving	0	158	197	1135	1406	1669
% / Branch 37	0%	0.9%	0.9%	4.4%	4.5%	4.6%
% / Furnaces	0%	6.7%	6.7%	32.3%	32.3%	32.3%
CO2 emissions (10^3 Ton)						
Branch 37 (Baseline)	2840	3928	4684	5542	6665	7745
Furnaces (Baseline)	532	796	993	1178	1460	1732
Reduction	0	53	66	381	472	560
% / Branch 37	0%	1.3%	1.4%	6.9%	7.1%	7.2%
% / Furnaces	0%	6.7%	6.7%	32.3%	32.3%	32.3%
Final user costs (million $)						
Branch 37 (Baseline)	972	1541	1803	2151	2556	3623
Furnaces (Baseline)	40	58	69	84	99	138
Mitigation	0	17	20	21	25	27
% / Branch 37	0%	1.1%	1.1%	1.0%	1.0%	0.7%
% / Furnaces	0%	29.5%	29.0%	25.0%	25.0%	19.5%

Table 3.14.
Basic Data for Passenger Vehicles by Type (1990)

Vehicle Type	Efficiency (10^3 Pass Km/BOE)	Capacity (10^3 Pass Km/Year)	Investment (10^3 $)	Operation & Maintenance ($/10^3 Pass Km)
Private				
New	1.29	19.48	10.00	7.75
Old	0.97	16.49	0.00	58.76
Public				
<12 Seats gasoline				
New	3.17	168.01	15.00	2.52
Old	2.62	154.58	0.00	17.94
12-32 Seats gasoline				
New	7.40	407	26.00	1.35
Old	5.76	357.12	0.00	9.90
>32 Seats gasoline				
New	15.20	836.00	100.00	0.66
Old	10.82	670.84	0.00	5.27
12-32 Seats diesel				
New	6.66	406.26	26.00	1.35
Old	5.31	361.08	0.00	9.79
>32 Seats diesel				
New	13.70	839.81	100.00	0.58
Old	10.07	694.83	0.00	4.87
Vehicle Type	Efficiency (10^3 Ton Km/BOE)	Capacity (10^3 Ton Km/Year)	Investment (10^3 $)	Operation & Maintenance ($/10^3 Ton-Km)
Freight				
2 Axle light Gasoline				
New	0.26	10.74	20.00	30.77
Old	0.19	8.74	0.00	
2 Axle heavy Gasoline				
New	0.74	43.22	40.00	13.51
Old	0.54	34.56	0.00	105.56
2 Axle heavy Diesel				
New	0.68	42.84	40.00	14.71
Old	0.53	37.10	0.00	107.55
3 Axle gasoline				
New	3.27	215.82	60.00	13.06
Old	2.31	168.63	0.00	24.68
3 Axle diesel				
New	2.90	208.80	70.00	3.10
Old	2.23	178.40	0.00	23.32
4 Axle diesel				
New	4.81	533.91	100.00	1.66
Old	3.36	409.92	0.00	14.58

share was almost constant.

Heavy duty vehicle freight share increases 5.5% yearly throughout the period, while in the baseline case it is constant.

Table 3.15 presents energy savings, CO_2 emissions reduction, and mitigation costs for the final user.

Option 6: Reduced Private Vehicle Share

Private vehicle share in passenger transportation demand (pass-km) decreases in relation to the baseline case, while the share of large buses share increases according to the following assumptions:

-Private vehicles share is maintained at 34%; the yearly growth during 1990-2025 is 3.5%, while in the baseline case the share reached to 4% in 2025.

-Share of large buses increases from 23% in 1990 to 28% in 2025, which represents an increase of 4% per year.

Table 3.16 presents energy savings, CO_2 emissions reduction, and mitigation costs for the final user.

Option 7: Switching Gasoline to Natural Gas Vehicles.

Venezuelan government has initiated a plan to switch vehicles from gasoline to natural gas in public transportation, taking into account that the gas price is significantly

Table 3.15.
Switching to Larger Capacity Vehicles Mitigation Option Results

Year	1995	2000	2005	2010	2015	2020
Energy consumption (10^3 BOE)						
Baseline	74906	81335	87536	99378	117019	134263
Energy saving	962	3904	9383	12971	15990	18651
%	1.3	4.8	10.7	13.0	13.7	13.9
CO2 emissions (10^3 Ton)						
Baseline	31378	34073	36666	41621	49012	56326
CO2 reduction	394	1598	3840	5312	6556	7654
%	1.2	4.7	10.5	12.8	13.4	13.6
Final user costs (million $)						
Baseline	5301	7388	9348	11815	14652	16321
Mitigation	-57	-312	-784	-1115	-1428	-1617
%	1.0	4.2	8.4	9.4	9.7	9.9

Table 3.16.
Less Private Vehicles Share Mitigation Option Results

Year	1995	2000	2005	2010	2015	2020
Energy consumption (10^3 BOE)						
Baseline	74906	81335	87536	99378	117019	134263
Energy saving	407	974	1754	2804	4207	5644
%	0.5	1.2	2	2.8	3.6	4.2
CO2 emissions (10^3 Ton)						
Baseline	31378	34073	36666	41621	49012	56326
CO2 reduction	168	402	723	1156	1734	2327
%	0.5	1.2	2.0	2.8	3.5	4.1
Final user costs (million $)						
Baseline	5301	7388	9348	11815	14652	16321
Mitigation	-42	-111	-209	-345	-531	-684
%	0.8	1.5	2.2	2.9	3.6	4.2

lower than gasoline. The plan includes subsidies for motor conversion. The assumptions for this option are the following:

-Public transport demand is the same as in the baseline.

-10,000 small buses, 15,000 medium buses, 10,000 taxis, 25,000 light duty trucks will be converted by the year 2000..

-In 2000, public transportation demand that is satisfied by natural gas will be 7,073 passenger-km and 16,042 passenger-km in 2025.

-Energy intensity is the same for both gasoline and natural gas vehicles.

Table 3.17 shows the assumed characteristics for converted and new natural gas vehicles at the beginning of the program and Table 3.18 presents energy savings, CO_2 emissions reduction, and mitigation costs for the final user.

Table 3.17.
Natural Gas Vehicles Characteristics *

Vehicle Type		Operation/ Maintenence Costs	Efficiency	Investment	Capacity
Passenger		($/10^3 Pass-Km)	($/10^3 Pass-Km/BOE)	(10^3 $)	(10^3 Pass-Km/Year)
Taxis		30.00	0.97	1.90	16.50
	New	4.00	1.29	12.00	20.00
<12 Seats					
	Converted	9.00	2.62	2.20	154.00
	New	1.50	3.17	17.20	168.00
12-32 Seats					
	Converted	5.00	5.80	3.10	305.00
	New	0.07	7.40	2.90	407.00
Freight		($/10^3 Ton-Km/BOE)	(10^3 Ton-Km/BOE)	(10^3 $)	($/10^3 Ton Km/Year)
2 Axle light trucks					
	Converted	124.00	0.19	2.20	9.00
	New	15.50	0.26	22.20	107.00

* Dual system: NG/Gasoline

Table 3.18.
Switching Gasoline to Natural Gas Vehicles Mitigation Option Results

Year	1996	2000	2005	2010	2015	2020
Energy consumption (10^3 BOE)						
Baseline	74906	81335	87536	99378	117019	134263
Energy saving	-109	-493	-415	-241	-285	-296
%	0.2	0.6	0.5	0.2	0.2	0.2
CO2 emissions (10^3 Ton)						
Baseline	31378	34073	36666	41621	49012	56326
CO2 reduction	-0.5	127	428	839	1228	1228
%	0.002	0.4	1.2	2.0	2.5	2.2
Final user costs (million $)						
Baseline	5301	7388	9348	11815	14652	16321
Mitigation	-15	-129	-229	-300	-445	-438
%	0.3	1.7	2.4	2.5	3.0	2.7

Electricity Generation

In the baseline scenario, hydroelectricity generation increases by 88,544 GWh up to year 2011, remaining constant thereafter through the study period. After 2011, the increased demand is satisfied with natural gas thermal generation. Consequently, an increase in hydroelectric generation would contribute to a reduction in CO_2 emissions. Venezuela has an economically usable hydroelectrical potential in the High Caroni and Caura rivers, estimated at 10,000 MW of capacity and 65,000 GWh/year (Jimenez, 1995). Feasibility studies to develop this potential have been carried out, but without enough cost data to perform a complete mitigation assessment. However, an expanded case study of the power system including only the Tayucay project was carried out.

Option 7: Hydroelectrical Capacity Increase with Tayucay Power Plant

Project characteristics are as follows: Capacity: 3000 MW; Annual Energy: 15300 GWh;

Number of units: 6* 500 MW; Beginning of operation: 3 units by year 2012 and 3 units by 2013; and Cost: 2130 US$/KW.

The development of Tayucay plant would imply an investment cost increase of about US$700 million and a decrease of the operating and maintenance costs of US$72 million. Table 3.19 presents energy savings, CO_2 emissions reductions, and mitigation costs for the electricity generation system.

Summary of Mitigation Options Results

The cumulative impacts and costs for each mitigation option are summarized in Table 3.20. The most effective options are those in

Table 3.19.
Tayucay Plant Mitigation Option Results

Year	1990	1995	2000	2005	2012	2015	2020	2025
Energy consumption (10^3 BOE)								
Baseline	53184	17719	15116	16998	46855	64318	98590	130141
Energy saving	0	0	0	0	5779	11337	10118	10685
%	0	0	0	0	12	18	10	8
CO2 emission (10^3 Ton)								
Baseline	19565	5944	5071	5702	15719	21577	33075	43659
CO2 reduction	0	0	0	0	1939	3803	3394	3585
%	0	0	0	0	12	18	10	8
Electricity generation cost (million $)								
Baseline	452	330	339	397	482	521	618	707
Mitigation	0	0	0	0	113	111	129	145
%	0	0	0	0	23	21	21	20

Table3.20.
Cumulative Impacts and Costs of Mitigation Options (1990-2025)

Mitigation options		Energy saving 10^3 BOE	CO2 reduction 10^3 Ton	Total cost million $	Unit cost $/Ton CO2	% CO2 Reduction/ Baseline
Manufacture industry						
Steam generation						
Option 1	Boilers conversion	11602	7847	-120	-15.3	0.21
Option 2	Natural gas boilers	45137	15340	10	0.64	0.41
Direct heat						
Option 3	Iron reduction	57829	19400	1593	82	0.52
Option 4	Natural gas furnaces	25828	8665	692	80	0.23
Transportation						
Option 5	Switching larger capacity	372000	153000	-23613	-154	4.07
Option 6	Reduced private share	96000	39600	-9695	-246	1.05
Option 7	Switching to natural gas	-10000	20000	-3000	-146	0.53
Electricity generation						
Option 8	Tayucay project	144850	48594	1742	36	1.29
	TOTAL		312446	-32391		8.31
				Baseline CO2 emissions		3757950

the transportation sector, in terms of both emissions reduction and costs. The costs were negative for the three transportation options considered, which means that their application would provide benefits to the national energy system.

In the manufacturing industry, boiler conversion from liquid fuels to natural gas also reflects negative costs, but to a considerably lower extent than for the transportation sector. Likewise, the emissions reduction is also considerably smaller than in the other options. Improving the efficiency of natural gas boilers has almost no cost and is more effective in reducing emissions than boilers conversion.

Among the options showing a positive cost, improving the efficiency of natural gas furnaces presents the lowest total cost but is not very effective in reducing emissions. Therefore, it has a high unit cost that is very close to that of the option dealing with changes in the iron reduction process, which requires higher investments.

Increasing hydro generation has the highest total cost, but it is very effective in reducing emissions; compared to direct heat options, unit cost is less that half.

Figure 3.8 shows the "discrete step" curve in which the cost and the extent of the emis-

Figure 3.8.
Discrete Step CO_2 — Reduction Cost Curve

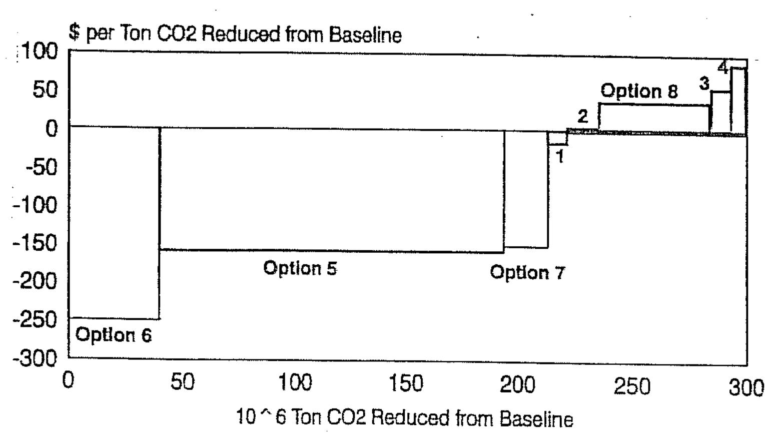


Table 3.21
Cumulative Costs of Energy Sector Mitigation Options

Mitigation option	CO2 reduction 10^3 Ton	Incremental cost $/Ton CO2	Total cost million $	Average cost $/Ton CO2
6	39600	-246	-9695	-245
5	192600	-154	-33308	-173
7	212600	-146	-36308	-171
1	220447	-15	-36428	-165
2	235787	1	-36418	-154
8	284381	36	-34676	-122
3	293046	80	-33984	-116
4	312446	82	-32391	-104

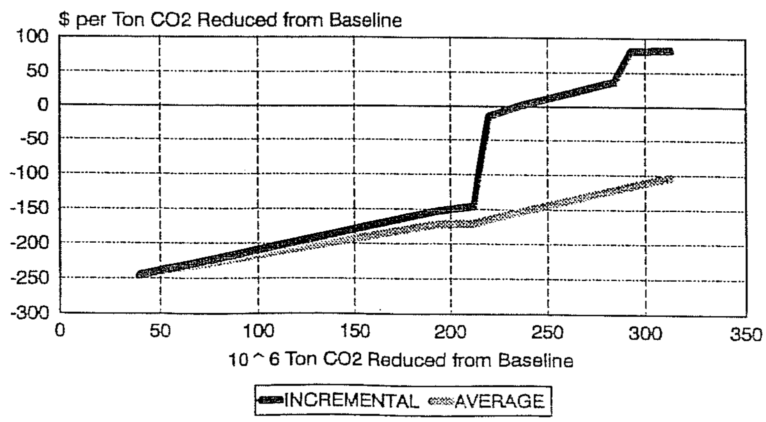
sions reduction of each of the alternative are presented. CO_2 emission emissions can be reduced by 220 million tons from the negative cost options, which represents 6% of CO_2 emissions in the baseline scenario.

Each mitigation option was analyzed separately. Neither the interdependency that may exist between them nor the effects that they may have in the energy system if they were jointly implemented have been assessed. However, it should be noted that they are highly independent actions, except for those in the transportation sector, and may require a few adjustments in order to apply them together. In spite of these limitations, and the small number of analyzed options, cost curves were built in order to have some global results for the energy system. Table 3.21 shows the estimated series for average and incremental costs while Figure 3.9 shows the corresponding curves.

In the energy sector, low energy prices represent the main barrier to any mitigation program. In spite of the last energy price increase, oil products and natural gas prices are still below the exportation FOB value and the marginal costs, respectively. Thus, energy is still only a small percentage of the users' cost structure, which limits interest in investments in energy use improvement programs. Even with the future price increases assumed in the baseline scenario, other types of measures will be needed to promote and encourage mitigation programs since users generally have other priorities and, in many cases, more attractive investment opportunities. Also, most users do not know how to achieve rational energy consumption and the associated benefits. Therefore, measures should include developing education and training programs, energy auditing, adequate financial mechanisms, and equipment standards.

Another important limitation to mitigation strategies implementation is the lack of institutional capacity and legal instruments for developing the mitigation measures. Venezuela does not have adequate institutional arrangements for energy demand management. Political decisions to implement mitigation programs and the allocation of financial resources for program pro-

Figure 3.9
Incremental and Average Cost Curves



motion and development are other important factors to be considered since any mitigation initiative, regardless of the associated economic benefits, requires adequate financing and human resources for planning and implementation.

4. Forest Sector

The mitigation assessment in the forest sector indicates that forest management and forest protection might be the most promising mitigation options for Venezuela. However, given the broad scope of the study and the data uncertainties, the results of this analysis should be viewed as a first attempt to evaluate the carbon benefits derived from the adoption of such measures.

Forest Resources and Greenhouse Gas Emissions

According to the last comprehensive study of vegetation cover in Venezuela, the forested area of the country in 1980 was roughly 57 million hectares (MARNR, 1982), which represents more than 60% of the national territory. About 75% of this forested land is classified as closed forests and more than 70% is located in the southern region of the country, where the Amazonian Basin is also located.

Policies for managing forest resources in Venezuela control wood production through two administrative approaches: annual permits and large concessions. Annual permits are provided to individuals on private and state lands for harvesting wood in wood lots smaller than 5,000 ha. Although tree harvesting is done selectively, this option does not guarantee sustainable production, and it is frequently viewed as the first step of the land conversion process, once the forest has lost its commercial value. The contribution of annual permits to national wood production has declined significantly: from more than 80% in 1983 to about 50% in 1990.

Large concessions are granted in wood lots located in forests that are legally protected for sustainable timber production. Of the 20 million ha of forests protected by law for this purpose nationwide, more than 2 million have already been given in concession to private companies for commercial forest management on areas ranging from 20,000 to 140,000 ha. The concessions are usually given for a period of 20 to 25 years. Under this scheme, the forest companies are requested to prepare a forest management plan, with a strong emphasis on silvicultural treatments in an effort to ensure sustainable production. Tree harvesting is also done selectively.

Forest plantations have reached nearly 500,000 hectares, of which about 95% are commercial plantations, primarily in the eastern region of the country and based mainly on one species, Caribbean pine (Pinus caribaea). The contribution of forest plantations to wood production has only become significant in the last few years, as the penetration of Caribbean pine in the national market has reached 10% (SEFORVEN, 1994).

Agriculture and pasture activities, as well as other development projects, have affected large areas of forest in the country. Logging is not considered to be a major cause of deforestation because wood production is based on a few species and trees are harvested selectively. However, logging leads indirectly to deforestation as the forest areas are opened up through road construction and are, consequently, subject to further intrusion by agricultural colonists.

The annual rate of forest clearing in Venezuela has not been consistently documented. Rough estimates have provided a wide range of figures on annual forest clearing, from less than 200,000 ha/yr (Catalán, 1984) up to 600,000 ha/yr (FAO, 1993). For the greenhouse gas emissions inventory, (CVCC, 1995), the average deforestation area was estimated to be approximately 517,000 ha/year during the last decade.

GHG emission from forest clearing were determined based on the Intergovernmental Pnel on Climate Change and the

Organization for Economic Cooperation and Development (IPCC/OECD) methodology. The emissions inventory indicates that deforestation accounts for about 44% of national CO_2 emissions (carbon emitted from disturbed forest soils is not included in this estimate). Biomass burning that occurs in conjunction with changes in land use is also an important contributor to trace gas emissions. Biomass burning accounts for approximately 5% of methane, 26% of nitrous oxides, 6% of nitrogen oxides, and 34% of carbon monoxide (CVCC,1995).

Uncertainties regarding estimates of GHG emissions from forest clearing are mainly attributable to data uncertainties with respect to deforestation rates and biomass densities. On the other hand, forests that are capturing carbon as a result of past human disturbances have not been included in the net carbon flux estimate due to the difficulty in tracking abandoned forest lands that are regaining vegetation cover.

Mitigation Options Analysis

An analysis of mitigation options in the forest sector needs to estimate how much carbon can be stored in vegetation and soil given a certain time period, management practices\site characteristics, implementation costs, land area for implementing the option, and the lifetimes of harvested biomass (IPCC, SAR, 1995). A key element to be considered is the type of sustainable forest practice that could be adopted in a given a country in order to mitigate carbon emissions.

In this study, the mitigation analysis for the forest sector deals with the options that have been traditionally considered priority government programs to manage, enhance and protect the country's forest resources. These options are: natural forest protection and management, establishment of industrial and small-scale plantations, and development of agroforestry systems.

The mitigation assessment involved the following steps: i) construction of a baseline scenario to determine possible trends of carbon emissions from forest clearing; ii) assessment of carbon storage in pilot forestry projects and associated costs; iii) construction of mitigation scenarios to assess Venezuela's potential for storing carbon, based on forest practices; and v) identification of main barriers to options implementation.

Baseline scenario

The baseline scenario in the forestry sector is based on the current trends of land use and consumption of forest products in the country (Sathaye and Meyers, 1995). However, one of the greatest limitations that most developing countries will probably have to face when developing this type of scenario is the lack of both reliable estimates on current land conversion from one use to another and long-term government plans that can provide future land use patterns.

The baseline for carbon dioxide emissions from land use change in Venezuela was developed using several assumptions regarding carbon emissions from forest conversion carbon sequestration and conservation in forest plantations and managed natural forests. The assumptions mainly deals with rough estimates of the rate at which lands will be converted to and from forest use. Estimates of carbon emissions and sequestration are based on the IPCC/OECD methodology for national greenhouse gas emissions inventory.

Growing pressure from organized communities and public concern for environmental protection are assumed to have a positive impact on forest conservation in the long term. Application of legal instruments to control illegal clearcuting and forest harvesting is also expected to show a slight improvement. In addition, several policies have been recently adopted by the Venezuelan Forest Service (e.g. natural forest management and native species plantations) to control and reduce degradation of natural forests. Thus, the area cleared annually is assumed to drop between 30% and

40% towards 2025, as a result of both implementing new policies and achieving better enforcement. It should be noted that, although seeking to protect forest reserves and promote sustainable management, these measures do not deal directly with the driving factors of forest conversion, which are agriculture and pastures activities. This fact, coupled with a limited institutional capacity for law enforcement and program implementation, is responsible for the rather conservative impact of these policies on average national deforestation.

On the other hand, the country experiencing an economic crisis that may already be affecting the process of land use change. Government subsidies for agricultural activities have been drastically reduced while high inflation rates have considerably increased the cost of developing new agricultural lands. This has produced an important reduction in wood consumption and production. Although the impact of such trends on future land use patterns are difficult to quantify, and could instead be temporary, it has been assumed that these trends could produce an additional 20% reduction in the base year's deforested area.

Thus the area cleared annually from 1990-2025 is expected to decrease steadily. From an average of 517,000 ha/yr, deforestation in the country will drop to 232,000 ha/yr by 2025, which implies a deforestation rate reduction of one third as compared to the 1990s. The total forest area of the country will then be reduced from 51.8 million ha in 1990 to 38.1 million ha in 2022 (about 75% of the base-year forested area would remain).

Carbon dioxide emissions from forest clearing (excluding emissions from disturbed forest soils) will reach about 54,000 Gg by 2025, a significant reduction with respect to the base year (84,790 Gg). Emissions do not decrease in proportion to deforestation because average biomass density of cleared forests was assumed to increase from 115 tons of dry matter per ha (t dm/ha) to 160 t dm/ha (Table 4-1). This increase in biomass density is based on the assumption that a great fraction of forest clearing will occur in the southern region of the country, whose forest areas have been less affected by human intervention than the northern region, where most of the population is concentrated.

Regarding carbon sequestration, the scenario assumes that annually planted area will be comparable to the average planted during the period 1970-90, reaching 20,000 ha/yr. This assumption is based on rough projections of ongoing and planned government and private plantation projects. On the other hand, the area of natural forest managed for sustainable wood production is estimated to double that of 1970-90 average, as a result of ongoing government policies to encourage the adoption of sustainable forest practices and improve harvesting control. An average of about 14,000 ha/yr of natural forests would then be added to the current commercially managed area. Based on these assumptions, annual carbon dioxide sequestration will reach about 11,000 Gg by 2025, double the base year figure (Table 4-2).

Net carbon dioxide emissions will reach

Table 4.1.
Forest Clearing Projections for Venezuela Baseline Scenario, 1990-2025

	1990	1995	2000	2005	2010	2015	2020	2025
Annual forest clearing 10^3 Ha	517	487	457	422	382	332	282	232
Deforestation rate	0.970	0.97	0.96	0.94	0.90	9.84	0.75	0.65
Average biomass density (tdm/ha)	15	125	140	154	160	160	160	160
Remaining forest area 10^3 Ha	51,830	29,320	46,900	44,760	42,750	40,970	39,430	38,150

Table 4.2.
Annual Carbon Dioxide Emissions and Uptake from Forest in Venezuela (10^3 Ton), Baseline Scenario, 1990-2025

	1990	1995	2000	2005	2010	2015	2020	2025
CO_2 Emissions from forest clearing	84,790	88.000	92,800	95,000	89,000	77,500	65,700	54,000
CO_2 Uptake from managed forests	5530	6300	7000	8000	8600	9500	10,300	11,000
CO_2 net emissions	79,270	81,700	85,800	87,000	80, 400	68,000	55,400	43,000

about 43,000 Gg, which represents a decline of approximately 45% with respect to the base year (79,260 Gg). In addition to lower deforestation rates, the increased area of managed forest reduces in net carbon dioxide emissions in this scenario.

Carbon storage in forestry projects in Venezuela

Two different forest projects, an industrial plantation (Uverito) and a managed protected area (Ticoporo Reserve), are used here as case studies in order to extrapolate this local experience to a broader context that includes carbon emissions reduction and sequestration. The main criteria for project selection were as follows: a) that the projects are successful or have high implementation potential, b) that they are applicable on larger scale in the country, c) that they are based on sustainable forestry practices, and d) that they cover a wide range of possible mitigation options.

Carbon sequestration potential and associated costs were evaluated for both the Uverito Plantations and the Ticoporo Reserve in order to assess the value of these projects as mitigation options (Bonduki and Swisher, 1995). The information and data used for developing the case studies were obtained from the Corporacion Venezolana de Guayana (CVG,1993) and the Venezuelan Forest Service (Seforven,1993). The carbon stock accounting method is from Swisher, 1991.

Uverito Plantations. This large plantation project in eastern Venezuela has been under development by a state company (CVG) since 1970. The project was initially designed for pulp and paper production, but due to delay in the construction of the pulp mills, the plantation will also produce sawn wood. By the end of 1993, 400,000 ha of caribbean pine had been planted, with an additional 100,000 ha planned over the subsequent three years (CVG, 1993). Potential agricultural productivity is very low and the most productive land use is likely to be timber production.

For the timber plantation project classification, net carbon accumulation is from new accumulated biomass and soil and from harvested biomass that enters long-term storage. The carbon storage density accumulated in plantations by new biomass is the long-term average biomass carbon over the period of rotation (Swisher, 1991). The rotation time of the Uverito project is 15 years, with a carbon density at maturity of 113 tC/ha, based on an annual biomass increment of 14.5 cubic meters per hectare per year (m3/ha-yr). The success rate for this type of project, which is privately managed with considerable investment and participation of local beneficiaries, is assumed to be 80%. The net carbon storage is estimated to be 62 tC/ha.

The total investment cost of the project, including funds for maintenance, administration, training, and research until the plantation begins to yield a positive cash flow, is \$1088/ha. This value does not include any opportunity cost for the land on which the project is implemented, because forestry is the highest-value land use available. The calculations give a net carbon storage of 6.2 MtC for 100,000 ha of new plantations, at a net cost of \$17/tC.

Ticoporo Reserve. The Ticoporo reserve is a large protected forest area of about 188,000 ha, decreed by the national government in 1955 for sustainable timber production. However, almost 40% of its forest area has been illegally cleared by agricultural colonists, mainly for pasture activities. Two private concessions for timber production have been given in two lots of more than 100,000 ha that are relatively well protected from illegal occupancy.

In 1993, the Forest Service designed a program to reestablish the forest cover and foster sustainable forest practices in the reserve. According to this program, the areas that will be dedicated to each type of land use at Ticoporo include about 24,000 ha for plantations and 26,000 ha for agroforestry. An additional 22,000 ha will remain as protected forest reserve land; 16,000 of natural savanna will be protected as wildlife refuge; and the remaining 100,000 ha of natural forest land will continue to be managed for extraction of marketable timber products, while maintaining the forest cover without intensive harvesting (Seforven, 1993). Potential agricultural productivity of the area is low, and the most productive land use in most areas is likely to be timber production and mixed agroforestry systems.

The changes in land-use patterns, and corresponding carbon storage densities that result from the planned projects can be calculated based on the differences between the plans and the reference case. These two cases show large areas of forest that would have been converted to low-productivity farm and pasture, but instead will be developed into agroforestry, intensive plantations, and both managed and protected natural forest areas. The resulting carbon storage is the difference in carbon densities on the land areas with different types of use between the plan and the reference case.

For the plantation projects, net carbon accumulation is from new accumulated biomass and soil and from harvested biomass that enters long-term storage. Agroforestry projects can store carbon through these mechanisms as well as by protecting existing forests from potential deforestation. The predominant species in these projects are Tectona grandis, Pinus caribeae, Cordia alliodora, Tabebuia rosea, and pithecellobium saman. It is estimated that equal areas of each species will be used. Total carbon storage by species is presented in Table 4-3.

The costs of the projects include materials, plantation, maintenance, infrastructure, vehicles, equipment, forest protection, fire protection, research, education and extension. Total costs are $905/ha for plantations and $550/ha for agroforestry, including opportunity costs for the land. The resulting total carbon storage values are based on a success rate of 60% in plantations and 70% in agroforestry for this type of project, which is managed by Seforven with high levels of investment and participation by local beneficiaries.

In protected forests, net carbon is stored in the standing biomass and soil on land that is protected from degradation. Thus, a large amount of carbon can be saved by protecting native forests from deforestation and by soil carbon accumulation resulting from forest protection and less intensive land uses than farming and pasture. The cost of the

Table 4.3.
Total Carbon Storage by Species in Ticiporo Reserve

Species	Growth m^3/ha-yr	Rotation time(yr)	Product decay rate	Soil carbon accumulation	Total tC/ha
Pinus careba	10.0	15	2.0%	15%	53
Tectona grandis	9.0	20	1.5%	15%	79
Pithecellobium saman	5.0	25	1.5%	25%	54
Cordia alliodora	3.2	25	1.5%	15%	35
Tabebuia rosea	3.0	30	1.5%	25%	39

forest reserve is assumed to be the opportunity cost of land, $375/ha.

Under natural forest management, the net carbon storage is from standing biomass and soil and from harvested biomass that enters long-term storage. The costs for this type of project type are uncertain, but a total cost of about $700/ha, including the opportunity cost of land was estimated.

The total net carbon storage for all the project types is thus 11.6 million tons of carbon (MtC) at an average cost of $10/tC. The costs and carbon storage results for each project type are summarized in Table 4-4.

Mitigation scenarios

The results of carbon storage densities and associated costs of the case studies are used to determine the amount of carbon that might be stored under two different scenarios: a technical potential scenario and a constrained scenario. In both cases, the analysis of mitigation options includes two broad categories of feasible sustainable forestry practices that can generate not only economic, social, and environmental benefits, but can also produce carbon benefits by conserving and sequestering carbon. These two categories are: (1) management of existing forests to avoid or reduce carbon emissions; and (2) management to expand forest cover and carbon storage in the country.

We then demonstrate Venezuela's physical and technical potential for reducing net carbon emissions based on forest management options, excluding the influence that other factors may have on the actual applicability of these management options. The following mitigation options are included: forest protection, forest management in small areas, forest management in large areas, small scale forest plantations, industrial plantations, and agroforestry systems.

The technical scenario is based on estimates of the amount of land technically suitable for the development of mitigation options, without considering socioeconomic, legal, and other limitations. However, the potential land areas that could theoretically be fully allocated for mitigation options development were adjusted in order to avoid overestimation of carbon sequestration potential. Consequently, the results of this scenario might be considered a rather conservative upper limit to the amount of potential carbon storage through the adoption of proposed options. In this scenario, the mitigation analysis was carried out only for year 2025.

Estimates of available land for each mitigation options relied mainly on i) some studies that have characterized potential land use of the country, based only on physical parameters (MARNR, 1982, and 1991), and ii) on assumptions made on the amount of lands that could be allocated for mitigation options development, based mainly on technical considerations. For the options that deal with forest protection and management, potentially available areas were also analyzed within the context of the baseline scenario in order to assess the amount of forest that could be subject to sustainable management practices. The total amount of land potentially available for mitigation options implementation has been estimated to be about 19.7 million hectares while total carbon storage reaches 1,437 MtC (Table 4-5). Based on the results of average unit mitiga-

Table 4.4
Carbon Storage by Project Category for Ticoporo Reserve

Project type	Land area (103 ha)	Carbon storage density (tC/ha)	Total carbon storage (MtC)	Cost $/ha	Cost $/5C
Plantation	24	52	1.3	905	17
Agroforestry	26	27	0.7	550	20
Forest reserve		22	94	2.1	375
Managed forest		100	75	7.5	700
Total	172	62	11.6	630	10

Table 4.5
Potential Forest Mitigation Options and Carbon Storage in Venezuela, Year 2025, Technical Scenario

Mitigation option	Potential area (103 ha)	Carbon storage density (tC/ha)	Total potential carbon storage (MtC)	Unit cost ($/tC)
Protected areas	4000	94	376	4
Forest management small areas	600 - 1000	75	45 - 75	9
Forest management large areas	9000	75	675	9
Small scale plantations	310 - 470	52	16 - 24	17
Large scale plantations	4500	62	279	17
Agroforestry system	1000	27	27	20
Total	19690	-	1437	-

tion costs from the two case studies, total investment cost for this scenario has been estimated to be about US$ 13.7 billion.

The constrained scenario tries to provide a more realistic picture of the country's potential to store carbon, since socioeconomic factors may limit the actual availability of land for the purpose of storing carbon. However, given the difficulties in assessing the influence of economic, institutional, legal, demographic, and cultural factors on present and future land-use decisions, estimates of the land area that could actually be allocated for each mitigation option was based mainly on rough projections of a feasible development of the forestry sector in Venezuela by 2025. The total land area in this scenario represents less than 50% (about 9 million ha) of the total suitable land estimated in the technical scenario. Total carbon storage in this mitigation scenario reaches 695 MtC by 2025 (Table 4-6). Based on the results of average unit mitigation costs from the two case studies, total investment cost for this scenario has been estimated to be about US$ 5.7 billion.

Summary of Mitigation Options Results

This general analysis of mitigation options in the forest sector shows that there is a considerable potential in Venezuela for reducing CO_2 emissions through the adoption of sustainable forest practices, especially by slowing the rate of forest loss and degradation. Maintenance of already existing biomass in natural forests should therefore be the priority measure to reduce the amount of carbon released to the atmosphere. More importantly, forestry projects designed within the context of climate change issues basically deal with deforestation, which is a significant environmental problem in Venezuela.

Based on the two case studies and the mitigation scenarios, forest protection and management of native forest are the two options

Table 4.6
Carbon Storage Potential in Venezuelan Forest under the Constrained Scenario (2000-2025)

	Area (10^3 ha)				Carbon storage (million tC)			
Mitigation option	2000	2005	2015	2025	2000	2005	2015	2025
Protected areas	400	1100	1700	2300	37.6	103.4	159.8	216.2
Forest management —small areas	25	105	225	375	1.9	7.9	16.9	28.1
Forest management — large areas	1200	2800	3900	5200	90.0	210.0	292.5	390.0
Small-scale plantation	15	30	110	225	0.8	1.6	5.8	11.7
Large -scale plantation	35	105	450	700	2.2	6.5	27.9	43.4
Agroforestry system	10	25	80	210	0.3	0.7	2.2	5.7
Total	1685	4165	6465	9010	132.8	330.1	505.1	695.1

with the highest carbon conservation potential and the lowest carbon unit cost. Stopping or drastically reducing deforestation, through the application of effective measures to protect native forests, may appear to be a rather simple and high-impact alternative for offsetting greenhouse gas emissions. However, the primary causes of forest clearing in Venezuela are not related to forest activities and, consequently, the definition of feasible mitigation options will depend upon a good understanding of other economic sectors and how they account for land-use change. Land tenure, rural poverty, political interests, and weak implementation of land-use planning instruments and environmental laws are considered to be key limitations to any effort dealing with forest conservation efforts.

Expansion of the forest cover through the development of intensive forest plantations also has high potential to offset carbon emissions in the country. However, this option may be considered more applicable in the long run, due to the higher costs involved in the development of this type of project. Land tenure, economic factors, and lack of incentives represent some of the most important barriers to the development of forest plantation and agroforestry systems. Community participation, local benefits, institutional capacity and competence, as well as the involvement of non-government organizations are other relevant issues that need to be addressed in an assessment of forestry projects for offsetting carbon emissions in Venezuela. Given the social issues involved in the land-use change processes that have characterized Venezuela, a closer analysis of the main constraints and opportunities for implementing of mitigation options should consider non-carbon benefits as the key component of such initiatives.

The main limitation to this study is the uncertainty in the data used for forest conversion, biomass densities, and soil carbon, which in turn affect the reliability of both projected carbon emissions from land use change (baseline scenario) and estimated carbon storage potential in the two mitigation scenarios. Additionally, because the consideration of important factors other than land availability, such as socioeconomic and political constraints, would have a significant influence on the outcome of this study, the results obtained in this analysis should be viewed as a first attempt to evaluate the carbon benefits derived from the adoption of such measures. Some of these factors should be addressed in the near future in order to provide a more accurate picture of the feasible alternatives for reducing Venezuelan carbon emissions through forest practices.

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